

Effect of Varying Collar Heights of Multi-unit Abutments on Stress Distribution at Implant Abutment Junction: A Three-Dimensional Finite Element Analysis

K. Sravya*, D. Vikram Raj, K. Subash Chander, Abusaad Siddiqui, B. Vidhu Priya, Shadan Fatima

Department of Prosthodontics Crown and Bridge, Sri Balaji Dental College, Hyderabad, Telangana, India.

Abstract

Aim: The objective of this study is to evaluate effect of varying collar heights of multi-unit abutments on stress distribution at implant abutment junction using three-dimensional finite element analysis. **Material and Method:** Three 3-D finite element models of an edentulous mandible restored with a prosthesis supported by 4 implants were reconstructed to carry out the analysis varying collar lengths (2,3 & 4mm) were constructed with two anterior parallel abutments and two posterior tilted abutments at an angle of 30 degree and were subjected to four loading simulations. The Von Mises stresses generated around implant abutment junction were localized and quantified for comparison. **Results:** It has been observed that maximum stresses were found in 4mm collar length around implant abutment junction when full mouth biting, anterior, lateral and posterior loads are applied. **Conclusion:** Within the limitations of this study, it can be concluded that stresses seem to increase at implant abutment junction with the increase in collar height.

Keywords: All-on-4, Collar height, Finite element analysis, Multi-unit abutment.

INTRODUCTION

Traditional dental implants have typically been inserted axially, aligned with the long axis of the intended tooth to accommodate axial forces. In cases of a fully edentulous jaw, there is frequently inadequate vertical height in the posterior regions due to bony resorption. This resorption may occur following tooth removal, and in the lower jaw, it may be influenced by the proximity of the inferior dental nerve, while in the upper jaw, it may be affected by the presence of the maxillary sinus. For the maxilla, sinus augmentation using a lateral window approach is essential, requiring an extended treatment duration of up to 5 months. In the mandible, bone augmentation through onlay grafts or nerve transposition may be performed to facilitate the placement of implants in posterior regions.^[1,2]

The “All-on-four” treatment concept developed by Paulo Malo involves the use of a full arch fixed prosthesis that is immediately loaded. This prosthesis is secured by four implants, strategically placed in either the maxilla or mandible. The “All-on-four” concept with straight and angled multi-unit abutments was developed to provide edentulous patients with

an immediately loaded full-arch restoration with only four implants—two placed vertically in the anterior region and two placed at an angle of up to 45° in the posterior region. Hence, the “All-on-four” concept utilizes two axially orientated implants in the anterior region and two tilted posterior implants.^[2]

It is essential for a successful implant therapy to achieve a dynamic equilibrium between biological and mechanical factors. Abutment selection according to collar length index is an important factor. Collar length is the measurement between the implant platform and the gingival margin. Abutment collar length is determined by the height of the emergence profile and the type of prosthetic restoration.^[3]

The multi-unit abutment is designed to restore both fully and partially edentulous arches, especially when employing the

Address for correspondence: Dr. Sravya K.
Department of Prosthodontics Crown and Bridge, Sri Balaji
Dental College, Hyderabad, Telangana, India.
Email: shravya.kothakonda93@gmail.com

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well-established all-on-four treatment method that is backed by clinical and scientific evidence.^[4,5] Various options are available to accommodate different soft-tissue anatomies, including straight and angled variants at 0°, 17°, 30°, and 45°, with multiple collar heights. Tilting the posterior implants helps avoid critical anatomical structures such as the mandibular nerve, foramen mental, and the maxillary sinus, thereby reducing the need for bone augmentation. Furthermore, this tilt repositions the implant-abutment connection toward the posterior of the mouth, decreasing cantilevers and enhancing prosthesis support. Angled multi-unit abutments facilitate the tilting of the two posterior implants, allowing longer implants to be placed in the anterior bone rather than the posterior, where bone resorption commonly occurs. This enhances bone-to-implant contact and diminishes the necessity for vertical bone augmentation.^[6,7]

All-on-four immediate function approach to rehabilitate a fully edentulous jaw combines tilted and parallel abutments with four implants placed in two parallel anterior abutments, two distal posterior abutments, and then loaded with a full fixed prosthesis. Tilting of distal abutments reduces cantilever thereby improving bone anchorage, and anatomic structure bypass, increases biting elements and polygonal surface area thereby achieving a more favorable stress distribution in bone.^[8-10]

Using three-dimensional finite element analysis, this study aims to evaluate the effect of varying collar heights on multiunit abutments on stress distribution at implant abutment junctions.

MATERIALS AND METHODS

The present study was conducted by the Department of Prosthodontics and Crown and Bridge, Sri Balaji Dental College with technical help from CADD Solutions Vijayawada using SOLIDWORKS software to simulate 3D finite element model of Mandible and ANSYS software for meshing and loading. Finite element analysis is a numerical method of structural analysis based on the principle of dividing a structure into a finite number of small elements that are connected with each other at the corner points and nodes [Table 1]. For each element, its mechanical behavior can be written as a function of the displacement of nodes [Table 2]. These nodes are subjected to certain loading conditions, resulting in the behavior of the model similar to the structure it represents. When a computer analysis is performed, a system of simultaneous equations can be solved to relate all forces and displacement at the nodes. From this the stress and strain contour can be established in each element and thus the whole body. In the study, 3D finite element models of a human mandible were simulated. The implants were designed according to a commercial implant system developed by ADIN. The material of choice used for implants was titanium.

The implants designed were 4.5 mm in diameter and 13 mm in length: Straight titanium abutments of 3.5 mm height were

Table 1: The Young's moduli and Poisson ratios of the materials used in the present study are mentioned

Materials	Youngs modulus (Gpa)	Poisson ratio (v)
Cancellous bone	1.37	0.30
Cortical bone	13.7	0.30
Implants and abutments	110	0.30
Titanium framework	110	0.28

Table 2: The number of nodes and elements arranged in above models are mentioned in

	2mm		3mm		4mm	
	Nodes	elements	Nodes	elements	Nodes	elements
Assembly	66290	344628	65923	342188	65980	342796
Implant	23870	80772	22897	76294	21914	75288
Abutment	7640	14384	7857	16544	7360	17992
Bone	50028	229428	50031	229428	49910	229428
Bar	6030	9252	5607	9252	4606	9252

used for anterior implants and posterior 30° angulated titanium abutments of 3.5 mm height were used for the posterior implants. The arc-shaped framework which is 4 mm in width and 3.5 mm in height was designed and joined to the abutments which presented 10 mm distal cantilever.

To compare the distribution of stresses on the implants of all the models, four loading situations (Full mouth biting load, anterior loading, lateral loading, and posterior loading) were simulated in each model.

RESULTS

According to the results obtained in the present study, it can be concluded that maximum stresses were found in 4mm collar length around implant abutment junction when full mouth biting, anterior, lateral and posterior loads are applied.

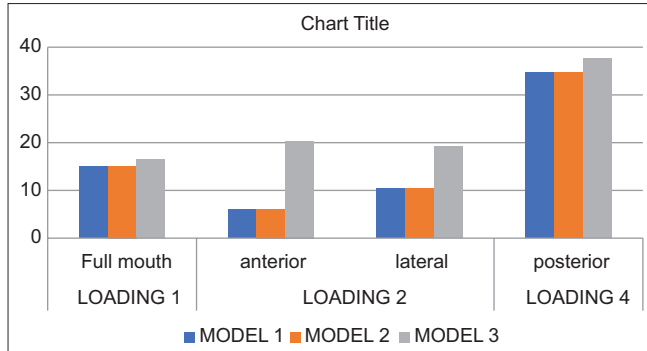
After the Finite element analysis, it can be further concluded that significant changes in Von Mises stresses were seen in bone (Graph 1), implant (Graph 2), implant abutment junction (Graph 3) under anterior load and lateral load and maximum Von Mises stresses were seen in prosthetic bar (Graph 4) and complete prosthetic assembly under anterior load (Graph 5).

According to study, we have observed Von Mises stresses, increased marginally between 2mm and 3mm collar height but significantly increased between 3mm and 4mm collar heights in all the loading conditions on Bone, Implants, Implant abutment junction, Bar and Prosthetic assembly.

DISCUSSION

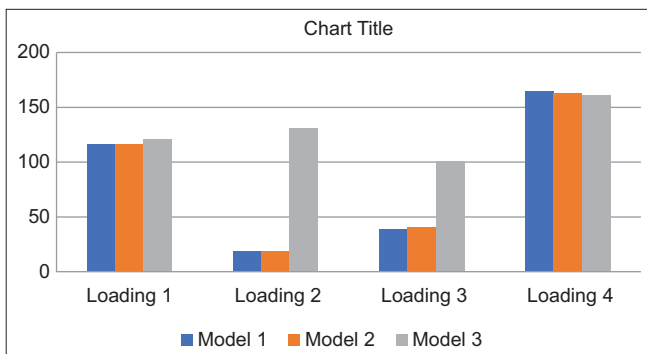
The distance between the top of the marginal peri-implant soft tissue and the implant platform determines the collar height. Abutment selection according to the gingival height index depends on two main factors:

Contents	Loading 1 Full Mouth	Loading 2 Anterior	Loading 3 Lateral	Loading 4 Posterior
MODEL 1 (2mm)	14.9933	5.99296	10.42	34.72
MODEL 2 (3mm)	15.149	6.09945	10.47	34.71
MODEL 3 (4mm)	16.5215	20.3207	19.13	37.63



Graph 1: The above chart shows different Von Mises stresses on the bone at different collar heights (2 mm, 3 mm, and 4 mm) under different loading conditions

Contents	Loading 1	Loading 2	Loading 3	Loading 4
Model 1 (2mm)	116.44	18.68	39.10	164.41
Model 2 (3mm)	115.95	19.05	40.48	162.43
Model 3 (4mm)	120.75	130.76	100.53	160.53

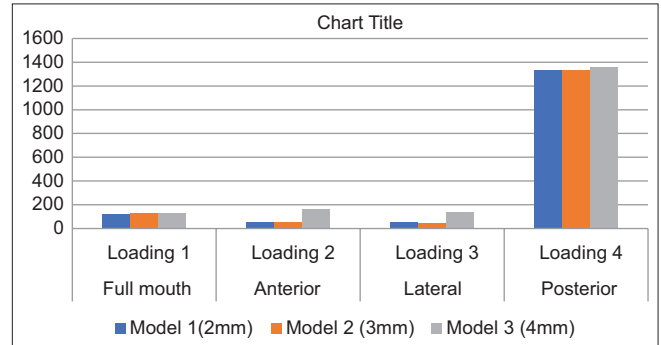


Graph 2: The above chart shows different Von Mises stresses on implants at different collar heights (2 mm, 3 mm, and 4 mm) under different loading conditions

(i) The depth of the gingival sulcus guided by the occluso-cervical gingival height (ii) The restorative vertical space. Patients with deeper gingival sulcus usually need longer abutment collars than patients with shallow ones.^[4]

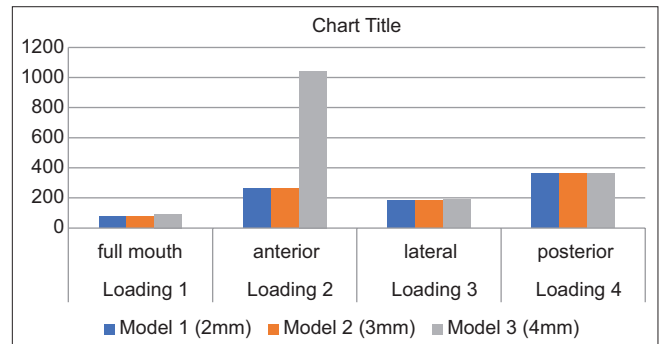
Collar length is the distance between the implant platform and the gingival margin. Significant vertical space that has not been corrected with vertical Ridge augmentation may necessitate the selection of longer abutments, which leads to a vertical cantilever. The selection of the length of the abutment collar would be affected if different distances between the implant platform and the gingival margin exist.^[4]

Contents	Full mouth Loading 1	Anterior Loading 2	Lateral Loading 3	Posterior Loading 4
Model 1 (2mm)	120	54.05	50.75	1334.44
Model 2 (3mm)	131	54.36	50.08	1333.04
Model 3 (4mm)	127	162.91	135.46	1354.92



Graph 3: The above chart shows different Von Mises stresses on implant abutment junctions at different collar heights (2 mm, 3 mm, and 4 mm) under different loading conditions

Contents	Loading 1 full mouth	Loading 2 anterior	Loading 3 Lateral	Loading 4 posterior
Model 1 (2mm)	78	264.47	183.99	363.34
Model 2 (3mm)	77	264.40	184.02	363.03
Model 3 (4mm)	93	1042.55	187.59	361.48



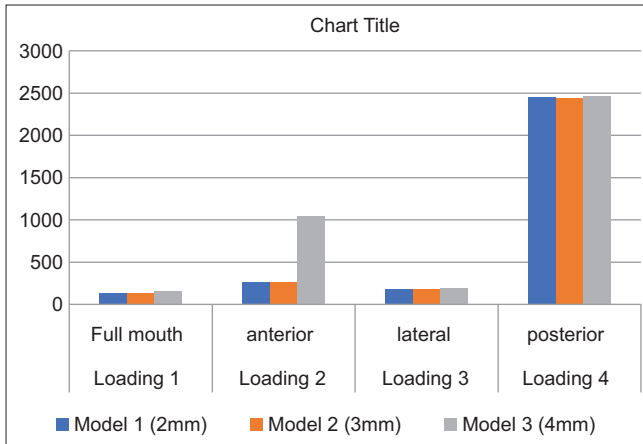
Graph 4: The above chart shows different Von Mises stresses on prosthetic bars at different collar heights (2 mm, 3 mm, and 4 mm) under different loading conditions

SUMMARY AND CONCLUSION

According to the results obtained in the present study, it can be concluded that maximum stresses were found in 4 mm collar length around implant abutment junction when full mouth biting, anterior, lateral, and posterior loads are applied.

It is assumed that all materials in finite element analysis are homogenous, isotropic, and linearly elastic. Moreover, ideal conditions were established, such as 100% contact between bone and implant and perfect fit of implants, abutments, and prosthetic bars with the absence of gaps or frictional coefficient.

Contents	Loading 1 Full mouth	Loading 2 anterior	Loading 3 lateral	Loading 4 posterior
Model 1 (2mm)	129	264.47	183.99	2446.96
Model 2 (3mm)	138	264.40	184.02	2437.65
Model 3 (4mm)	160	1042.55	187.59	2463.51



Graph 5: The above chart shows different Von Mises stresses on complete prosthetic assembly at different collar heights (2 mm, 3 mm, and 4 mm) under different loading conditions

These ideal simulations cannot be compared with intraoral conditions due to biological factors involving osseointegration of the implants which varies according to bone density.

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